Progress on algorithms for induction hit finding

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Overview

Currently DUNE focuses on hit finding in collection wires only

Looked at algorithms which would allow us to extend the hit finding to induction wires.

- Complementary to collection hit finding → better handle on systematics
- More hit information
  - Improved clustering efficiency for low energy physics

Main objectives for the algorithm:

- Convert from bipolar to unipolar waveform in real time

- Should improve S/N

- (Ideally) wouldn't require distinction between induction and collection wires.

Running sum (RS) algorithm

Integration algorithm for induction HF first developed in ICARUS.

I've built on previous work done in DUNE by Philip Rodrigues ([DUNE UK meeting](#)) & Aran Borkum ([DUNE-doc-22954](#)).
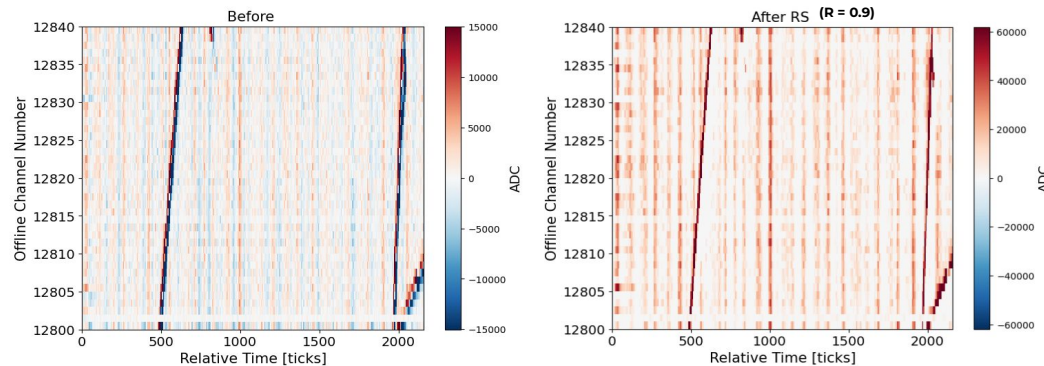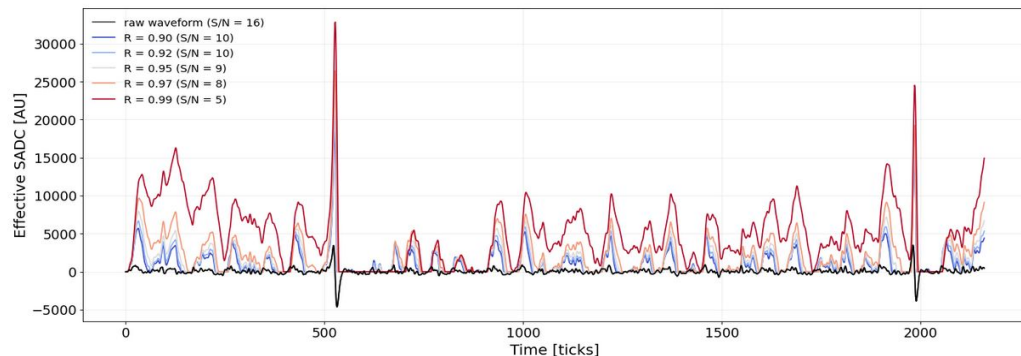
Basic RS algorithm:

$$I_{RS}(n) = R \cdot I_{RS}(n-1) + I_{RAW}(n)$$

- I_{RS} = effective SADC
- I_{RAW} = current ADC value
- R = weighting factor [0,1]

Main idea: Should act similar to deconvolution and help identify faint induction signals (see Philip's talk).

I tested some versions of the algorithm in the DUNE-DAQ READOUT module.

Integrated waveform traces out the original shape:

- Have to force unipolarity by setting negative waveform values to 0.

    → Losing some data.

- Signal and noise equally amplified.

    ○ Detrimental to the S/N.

*ADC data from the standard frames.bin file in DAQ readout.*

'Absolute' RS (absRS) algorithm

"Absolute" Running Sum (absRS): take the absolute value of I_{RAW} during summation
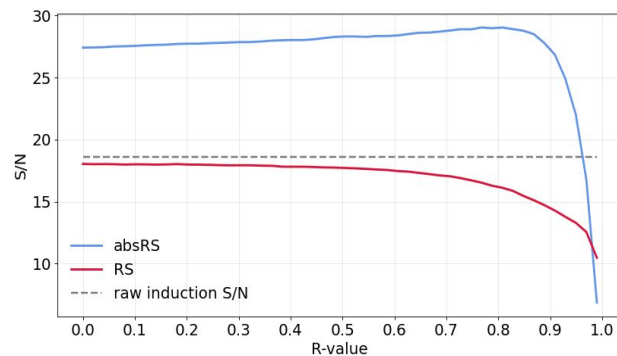
$$I_{RS}(n) = R \cdot I_{RS}(n-1) + \left| I_{RAW}(n) \right|$$

- Strictly unipolar waveform by definition.

- Sharp signal amplification due to positive contribution from the negative peaks.

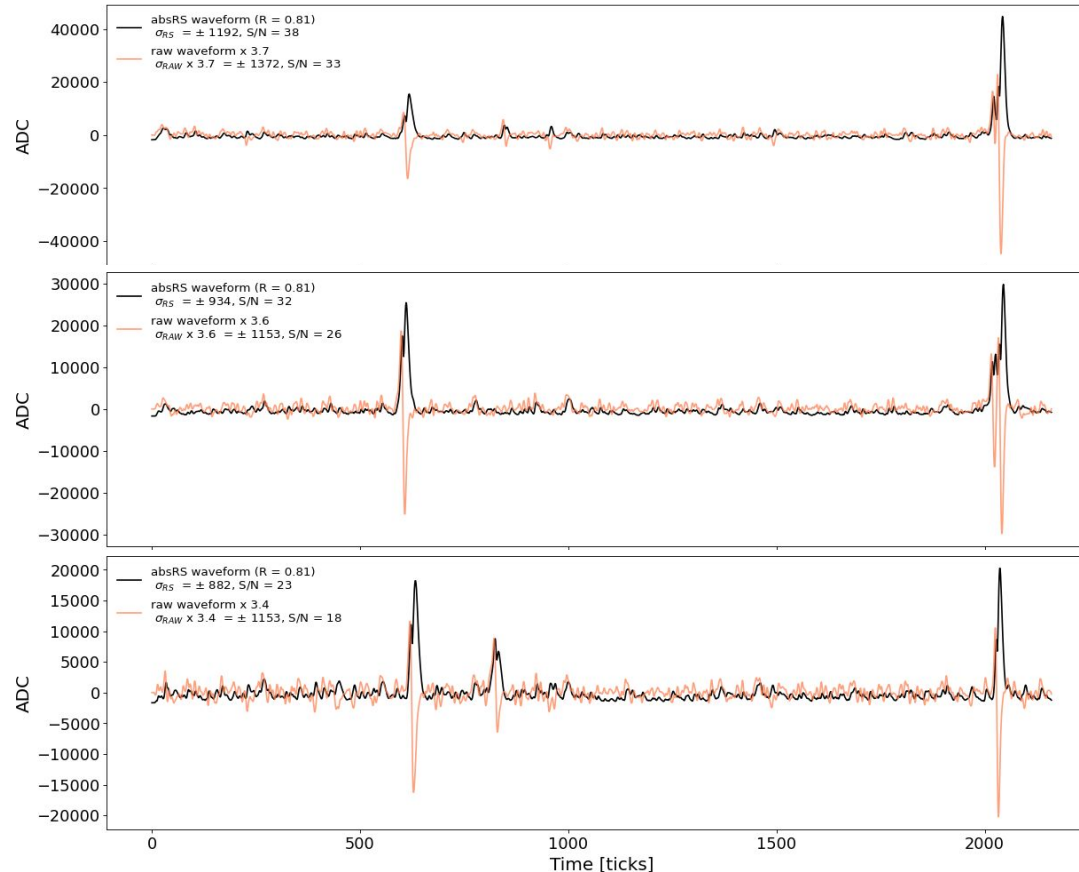- **Possible equal treatment for both types of wires in FEE**.

R-dependence

'Absolute' Running Sum
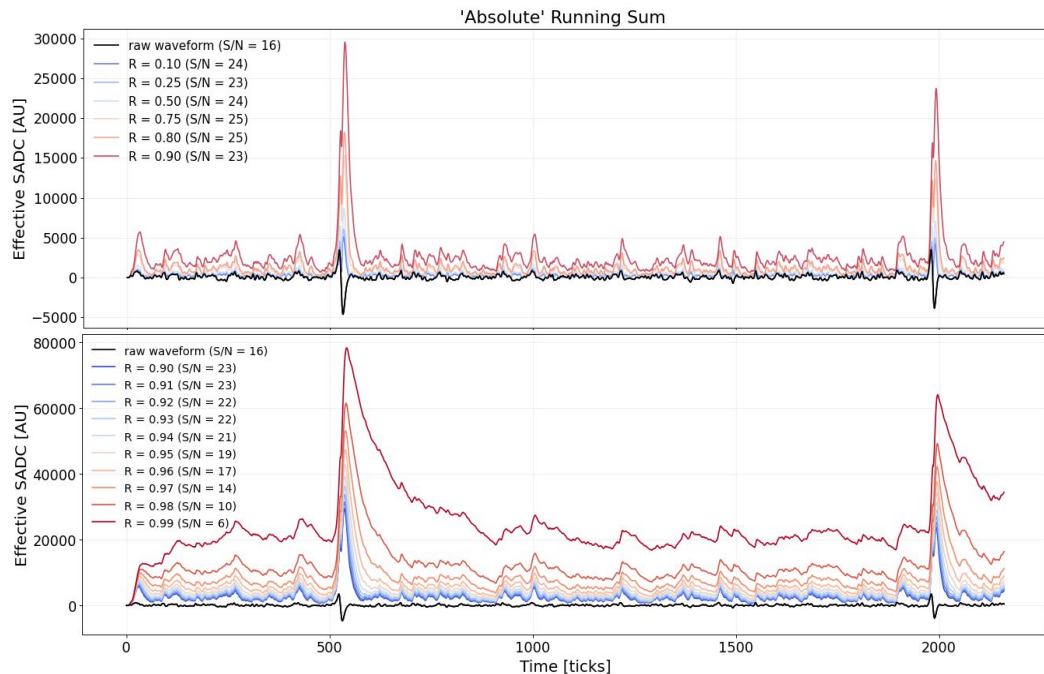
When absRS is close to being applied maximally (R > 0.9), S/N deteriorates due to sharp baseline shifts & peak deformation.

Average S/N for 160 induction wires in a sample vs R-value.

- **For absRS : S/N maximised at R ~ 0.81**
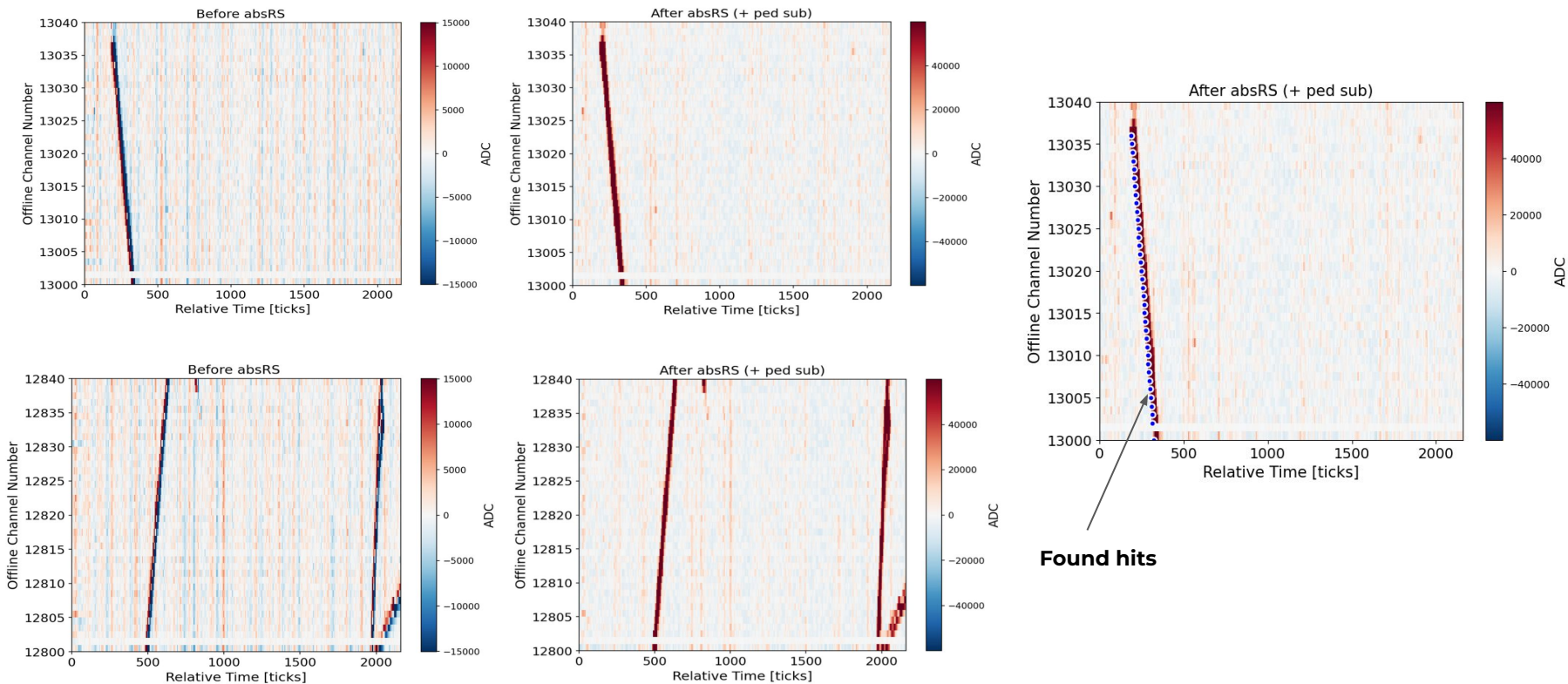 $(S/N_{absRS} = 29, \quad S/N_{RAW} = 18.6)$ ~ 50% increase in S/N

Two things at play give the improvement in S/N

1. Signal amplification
2. Noise smoothing

*absRS waveform after baseline subtraction
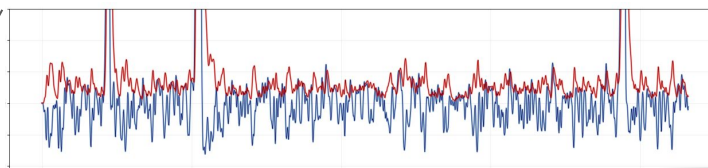
**raw waveform scaled such that the maximum peaks for raw and abs waveforms are the same size.
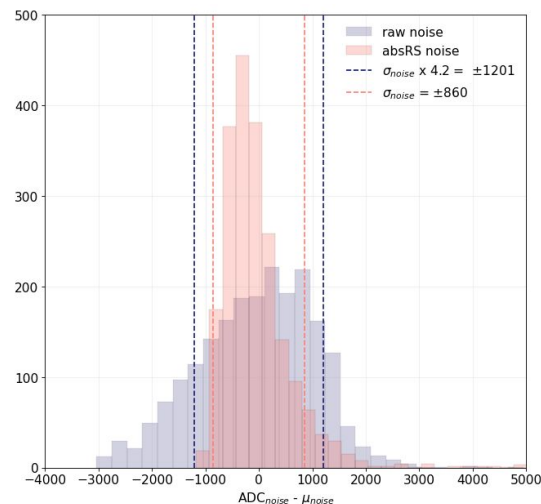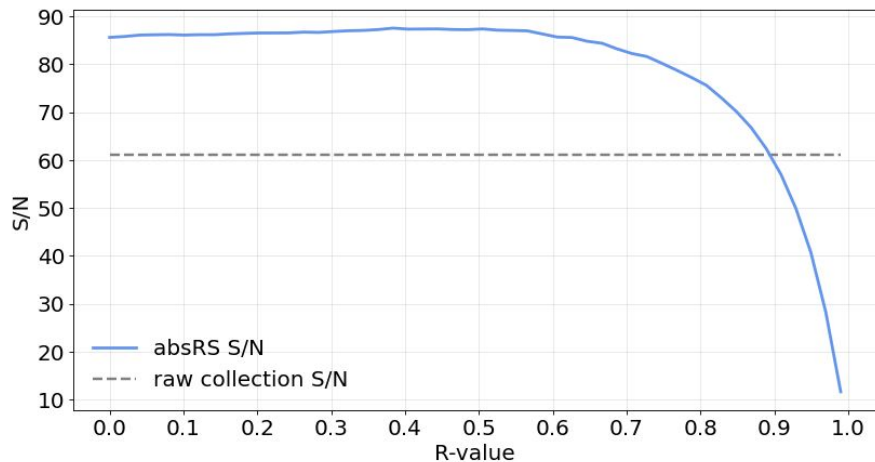
Signal processing with absRS

Found hits

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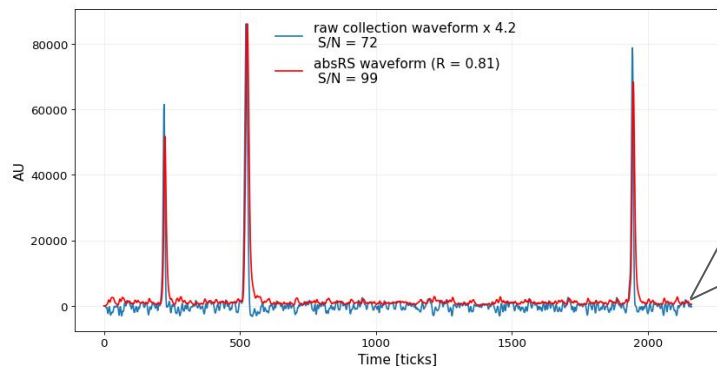
noise waveform

Collection wires also seem to benefit from absRS:

- σ_{noise} reduced by ~30% after absRS

- Peak profile largely unchanged

- Small baseline shift

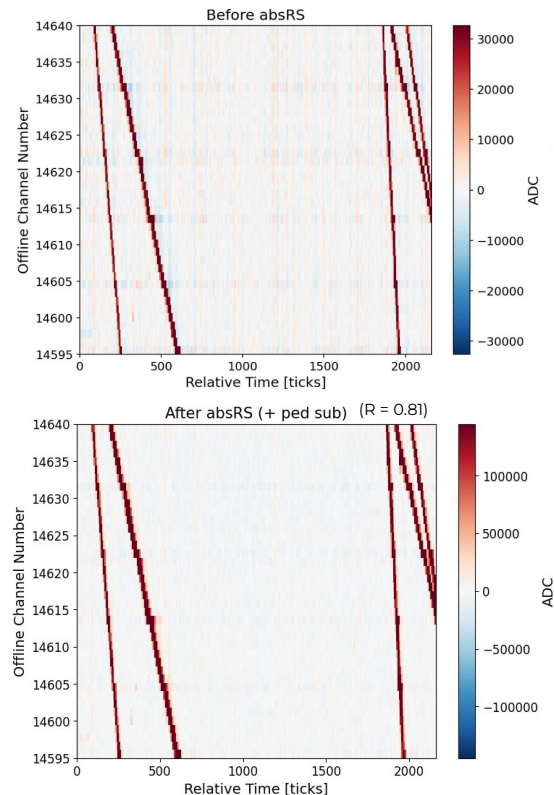- Overall improvement in S/N

S/N for collection wires

S/N maximised at R = 0.38:

S/N_{RAW} = 61.2 , S/N_{absRS} = 87.5 (~40% increase in S/N)

At R = 0.81:

S/N_{absRS} = 75.2   (~25% increase in S/N)
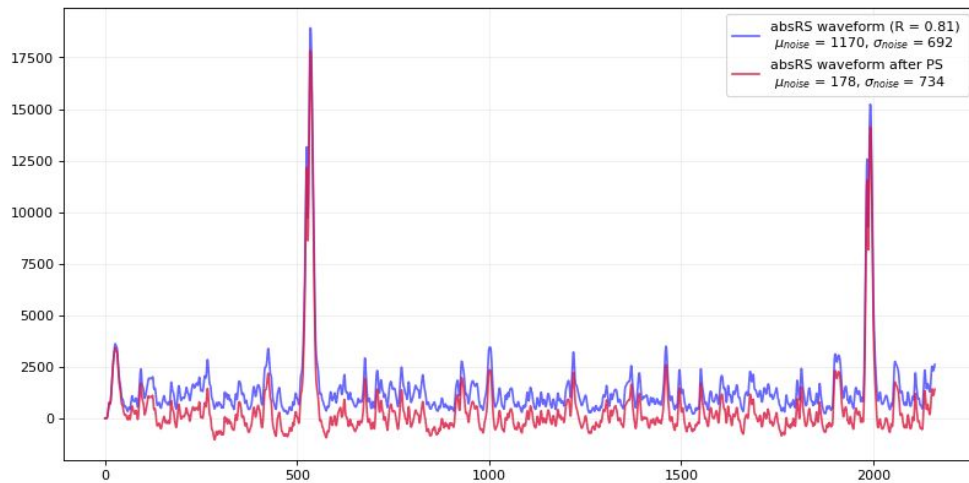
Baseline shift

Baseline shift is relatively small at R = 0.81.

Waveform can be shifted back using a Frugal Accumulator

- Same approach as to pedestal subtraction.

- Waveform stabilises quite quickly.

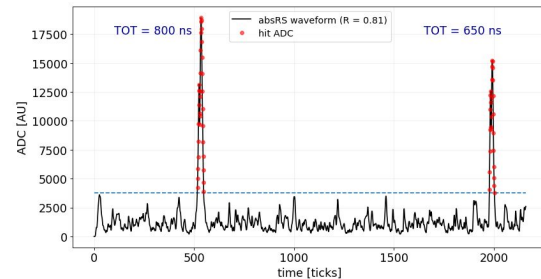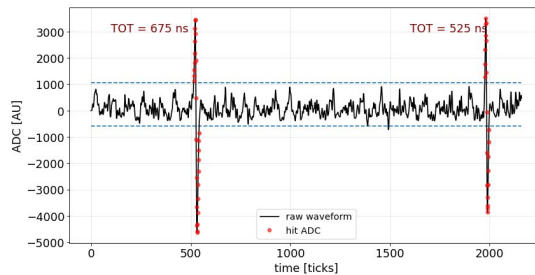- Due to amplified ADCs, works best when m is incremented by a large number (e.g. 100) instead of 1.

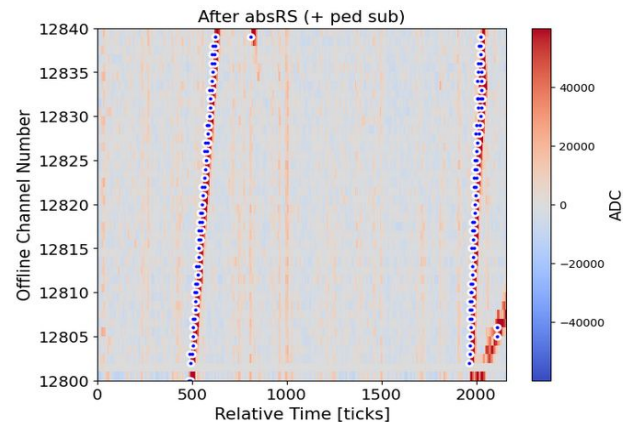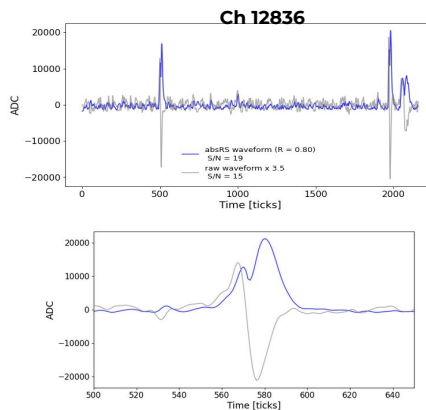**Would require pedestal subtraction to be applied twice during the HF chain.**

Signal saturation & overlapping hits

- absRS sightly extends the tail of the peak profile, increasing the TOT for hits (up to ~20%). Possibly could cause a build-up for 'busy' events.

Hit overcounting

- Double peak formed at the bipolar inflexion

Conclusions

- **absRS is a simple but powerful algorithm which could make induction hit finding easier**

  - Works for induction and collection channels.

  - Improves the mean S/N on raw waveforms.

- **But whilst solving some issues, it introduces new ones..**

  - Signal saturation & overlapping hits.

  - Bipolar peak turns into a slight "double peak" after the algorithm

  - Complications to the HF chain

- **Thiago Bezzera currently looking at low E physics efficiency performance of absRS.**

- **Antony Earle is looking into testing the algorithm in firmware.**
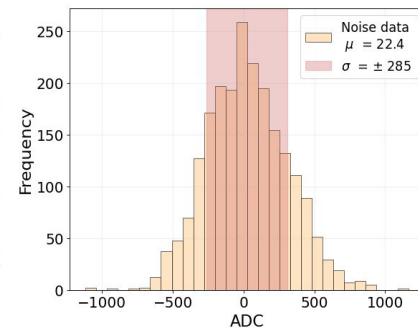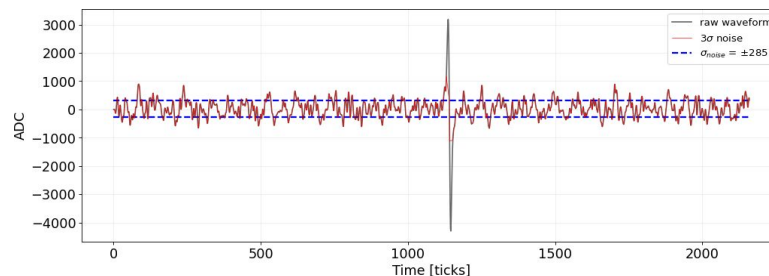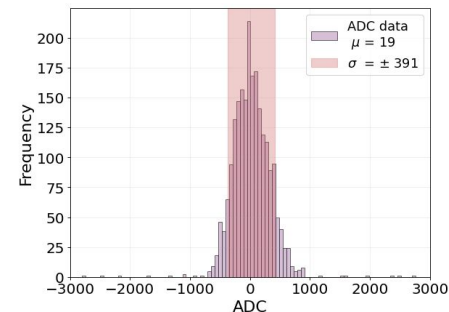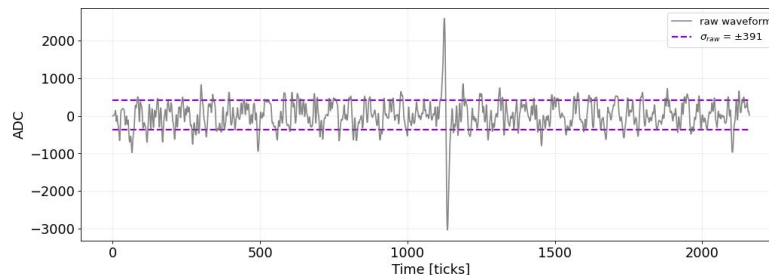
Backup slides

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Approach to estimating S/N

Estimating noise

- Get rough estimate of σ_{raw} from raw waveform

- Define $(\mu - 3\sigma_{RAW}) < ADC < (\mu + 3\sigma_{RAW})$ as **noise**
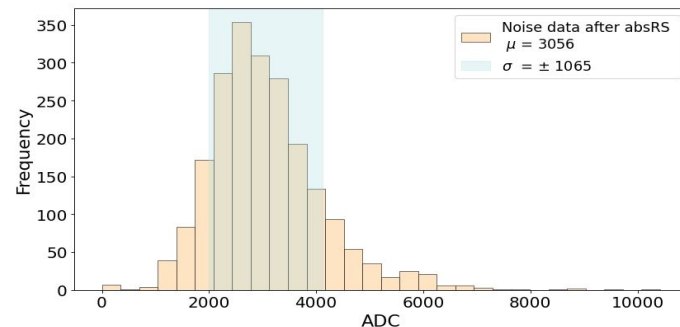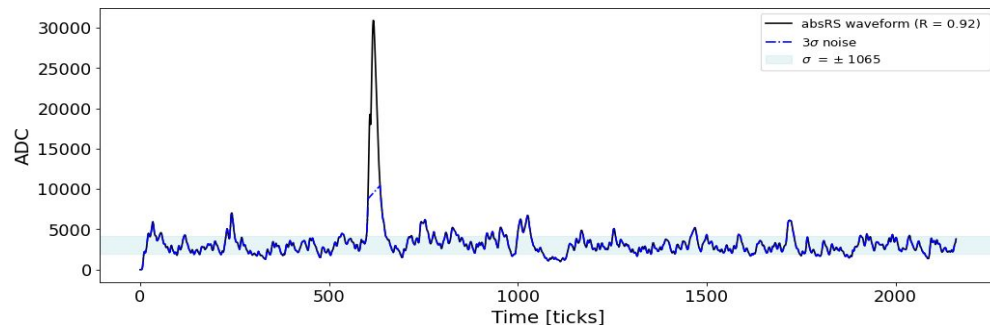
- Get σ_{noise} from the noise waveform

S/N = height of signal peaks/height of noise peaks (relative to μ_{noise})
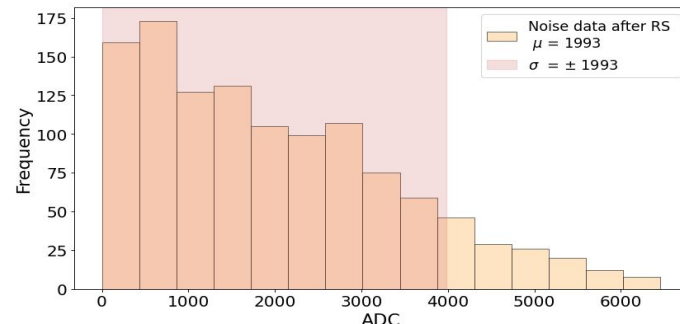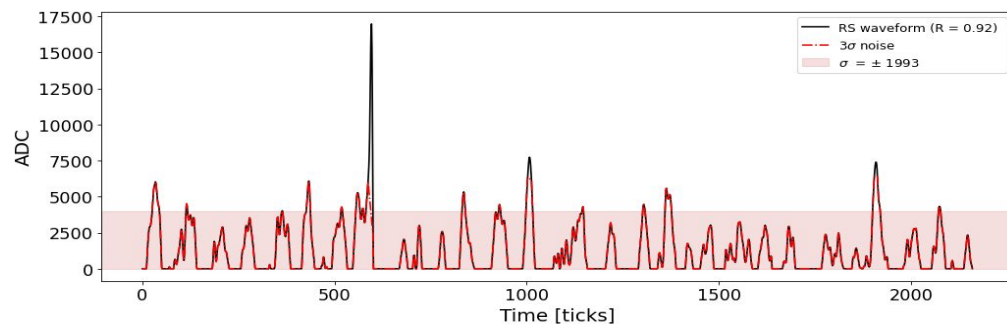
- S = max(|ADC|) - μ_{noise}

- N = σ_{noise}

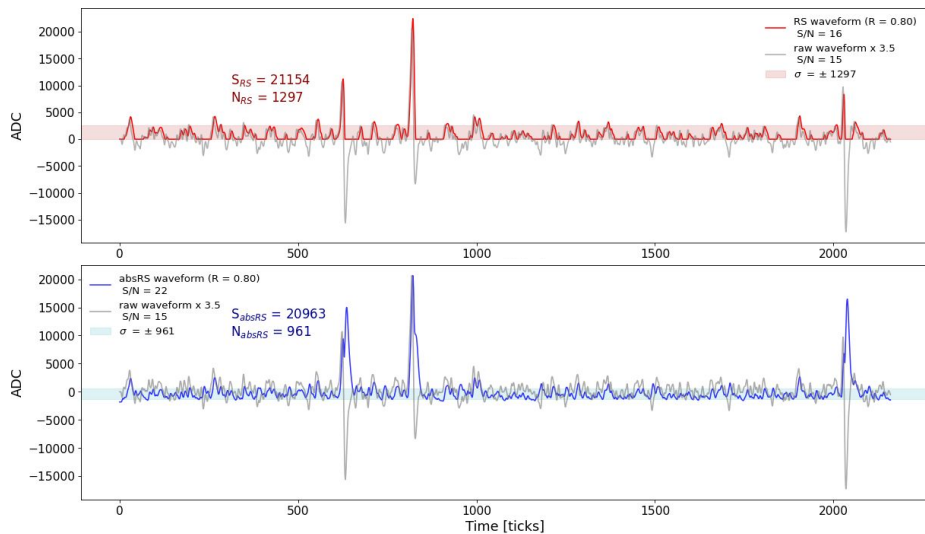Assuming **normal probability distribution** for noise on the **absRS waveforms**

Assuming **exponential probability distribution** for noise on the **RS waveforms** $\mu = \sigma = 1/\lambda$
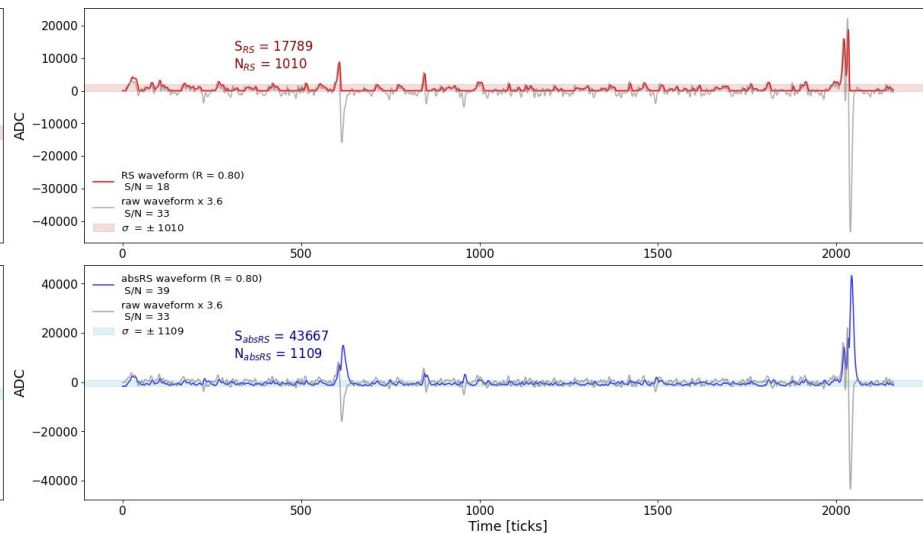(where λ is the rate parameter) <u>only including non-zero entries</u> .
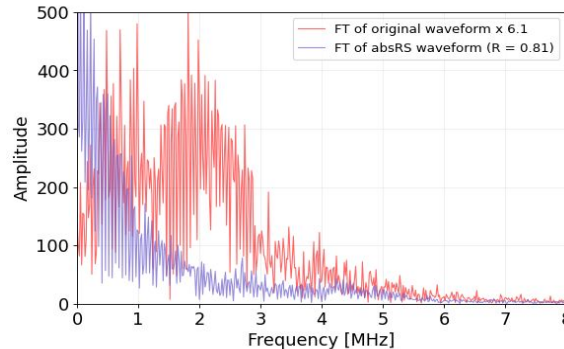

16

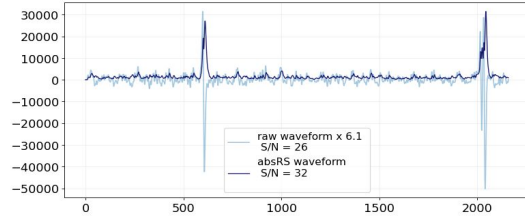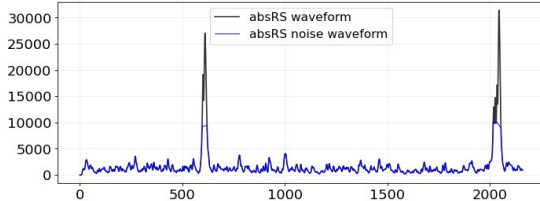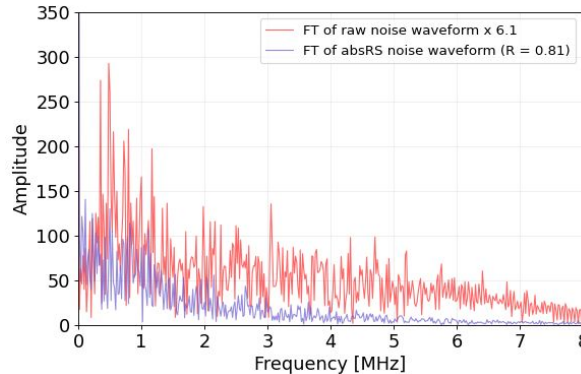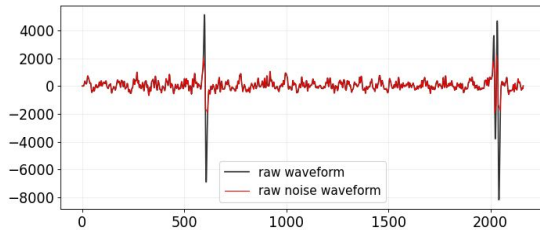# absRS vs RS waveforms

Channel A

Channel B

- absRS gives greater peak amplification (since there's no sharp fall into the negative part of the bipolar peak) while simultaneously achieving similar σ_{noise} to the RS waveform.

Fourier Analysis of the waveforms before & after absRS

1 tick = 25 ns
Sampling rate= 40 MHz

Top: FT for full waveforms
Bottom: FT for 'noise' waveforms

R-value appears to be different for induction/collection wires

- Suggests that R cannot be universally optimized

- Fundamental difference between collection & induction signals → the difference in optimum R-value between the two is not that surprising.

- The R-value dependence for the set of induction/collection wires shows that the overall dependence on R seems to follow the same pattern suggesting $R_{optimum}$ is not unique to each data set.

If $R_{optimum}$ is slightly different for different data sets, as long as R<0.9, running absRS algorithm will still give some improvement/won't be detrimental to S/N.
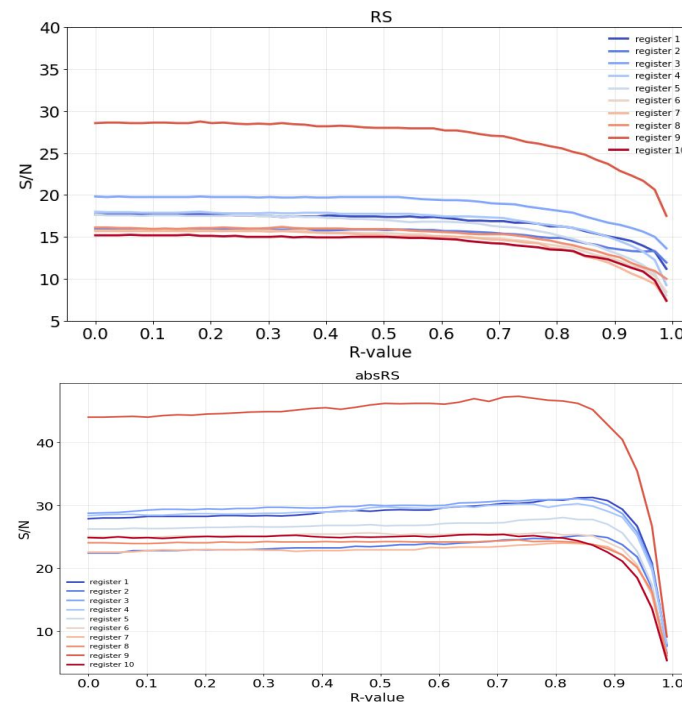
S/N dependence on the R-value for different induction registers (16 wires per register)

Induction wire hit finding (*Aran & Klaudia*) DUNE-doc-22954

- **Hit finder algorithm**
  - Running sum approach developed in ICARUS
  - Converts bipolar waveform to unipolar
  - $I_{RS} = R \cdot I_{RS}(n-1) + I_{raw}(n)$
    $R = 1 - \Delta t/\tau$
  - Possible equal treatment of all wires in the FEE

- **Application to clustering**
  - Pickup more information from induction wires
  - Construct induction plane clusters
    - Can run cluster matching to verify collection plane clusters
  - Running sum appears to favour SNB hits and eliminate a lot of the smaller background hits

- **Preliminary trigger efficiency curves**
  - Standard setup for clustering (see slide 4)
  - Standard clustering (green)
  - Standard clustering using time over threshold information (red)
  - Clustering on three planes with time over threshold information (black)
  - Significant increase in trigger efficiency at > 25 MeV
  - Needs to be updated given lower predicted neutron rate and Thiago's new triggering selection

26 Jan 2022   Thiago Bezerra   29